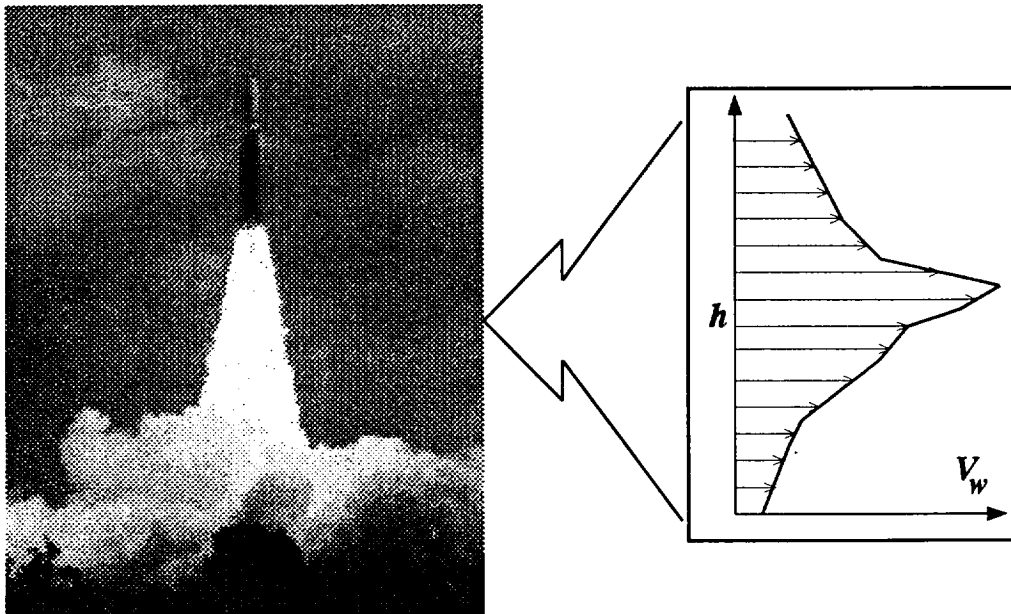


Contract # NAS 9-18879
Health Mangement and Process Demonstration

October 1995

Final Report: Wind Sensing, Analysis, and Modeling

Revision 1.0
28 October 95



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Prepared for:

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ABSTRACT:

The purpose of this task was to begin development of a unified approach to the sensing, analysis, and modeling of the wind environments in which launch systems operate. The initial activity was to examine the current usage and requirements for wind modeling for the Titan IV vehicle. This was to be followed by joint technical efforts with NASA Langley Research Center to develop applicable analysis methods. This work was to be performed in and demonstrate the use of prototype tools implementing an environment in which to realize a unified system.

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Mail Stop T330

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1. Introduction

1.1 Objectives

The analysis and design of space launch vehicles and the operational support of their missions requires data and models describing the wind environment in which they operate during endoatmospheric flight.

For example, mission analysis and design must ensure that the intended mission is feasible and then designs the trajectories to be flown with the appropriate wind environment models. Guidance analysis must design and validate a guidance system that can achieve the trajectory objectives in the presence of wind perturbations. Flight controls must design and validate an autopilot that will maintain vehicle stability and control during flight through the wind environment. Aero/thermal and structural loads analysis must confirm the vehicle's integrity in the presence of the induced aerodynamic loads.

The design and analysis processes that accomplish these functions require various types of wind data. Examples include velocity time histories or altitude profiles and information about the spectral content of those profiles. At present, each functional area is using the best locally-available data or 'traditional' models. These are often ad-hoc. A historical database that has been accumulated gradually over years of operations is the main source of wind profile data. Wind data has been gathered primarily through the use of radar-tracked meteorological sounding balloons.

It is desirable to improve the fidelity and accuracy of the wind modeling employed in analysis and design. This is particularly true for constraint-critical vehicles, such as the Titan IV. An expanded database with better information on factors such as wind persistence and weather correlation would be advantageous, as would be improved algorithms to process such data and assist in analyses requiring wind information. Better data will support improved analysis of performance versus availability and robustness issues for existing or proposed launch systems.

Wind sensing methods are emerging that will enhance or replace the existing balloon-based systems. Methods and tools must be established to support the use of these new systems and to make full use of the measurement data that they provide.

The main objective of this effort was to define requirements for the development of improved wind measurement, analysis, and modeling capabilities to support launch system design and operations. The areas to be covered included current and emerging sensing methods, data reduction methods, and synthetic wind model methods. Also to be considered was the information system infrastructure needed to support these methods and to facilitate efficient processes. A unified methodology should be established employing a central database and consistent data reduction and modeling techniques. (This would permit different engineering domains on system to design to the same data). Elements of such an infrastructure are prototyped by the developing Lockheed Martin PME (Process Management Environment), partially developed under internal research and development efforts parallel to this contract task.

Enhanced wind sensing, analysis and modeling eventually will permit improvements design and analysis functions requiring wind information. In Flight Controls on Titan IV, for example, design techniques are already in place that could take advantage of better wind information than is presently

employed. Such improvements will support the goals of improved operability required for future vehicles, such as RLV.

1.2 Approach

The approach to this study was to first derive a set of general requirements for a wind sensing, analysis and modeling system. A survey of the needs of an existing launch system, Titan IV, was the starting point. This was to be followed by investigation and development of analysis methods and initial development of a database by a joint effort between Lockheed Martin and NASA LaRC. The effort was to make use of the Lockheed Martin PME prototype tools to capture this development.

The Titan IV vehicle is sensitive to the wind environment and several of the analysis and design activities related to Titan IV operations employ wind data or wind models. Interviews were held with personnel in the Titan IV functional groups in order to ascertain their current usage of wind models and data. The types and sources of the wind data employed in each area for analysis and design were identified as clearly as possible. The information gathered is summarized in this report.

This data, as well as other general information on wind modeling was to be used to develop a basic set of requirements statements. These were to describe the properties needed to support each areas present processes. Any improved system of wind analysis and modeling must be able to support these existing needs in addition to facilitating future, improved launch system design and analysis processes.

1.3 Effort Descope and Termination

At the convenience of the customer this task has been descoped with respect to the original statement of work. The contract value was reduced an associated amount. The contractual details of this descope are in Amendment/Modification No. 7 to NAS 9-18879. The changes were made by agreement of the parties.

The full technical goals of this task could not be realized in part due to a lack of resources available to our technical partners at NASA LaRC to support the joint activities. Combined with resource shortages at Lockheed Martin, this cause the tasks initially to be deferred at our mutual convenience with the intent of completing them within an extended period of performance. Finally, it was deemed to be most expedient and convenient by our NASA LaRC technical partners for the task to be descoped and completed with the delivery of the material produced to date.

This document and the associated KMS database of material is delivered to fulfill the descoped task statements. The database includes the prototype PME tools that were to be used in the joint analysis and modeling algorithm developments. These prototype tools are delivered as limited rights data for the sole use of the customer. They are restricted to use by the customer internally or during joint activities with Lockheed Martin and must be protected from usage or access by third parties. The computer software underlying and realizing the PME functionality is copyrighted by Lockheed Martin. However, this shall not constrain the customer from showing or demonstrating to third parties the

customer's own work that is captured using these tools.

It is hoped that the goals of the task will be accomplished under future efforts. The requirement for improved wind sensing, analysis and modeling remains an issue for existing systems, such as Titan IV, and for new systems, such as RLV.

2. Background

2.1 Wind Sensing, Analysis and Modeling

Wind is an inherently complex and random phenomenon. Consequently, it must be analyzed and modeled using primarily stochastic methods. This requires a good database of measurement information, the tools to reduce that information and derive its statistical characteristics, and tools for developing synthetic wind profiles having those statistical characteristics for use in design. In order to use the natural, measured wind profiles in analyses, they must be sorted and correlated.

There are a number of approaches to modeling wind. Several general atmospheric models include wind information, based on averaged measurements or on calculation of winds based on distributions of bulk properties and atmospheric dynamics. Some models apply to specific locations, such as the Range Reference Atmosphere Models. These provide monthly and annual mean winds and are frequently employed for engineering studies and vehicle design. For information about such combined models, refer to the AIAA Guide to Reference and Standard Atmosphere Models, ANSI/AIAA G-003-1990.

The engineering of specific missions requires higher fidelity models or the use of measured wind profiles. In particular, persistence analysis and day of launch design and validation activities for a constraint sensitive vehicle such as TIV employ recently measured winds.

Wind measurement is accomplished by a number of methods. Major examples include radar-tracked balloons (e.g. "Jimspheres"), doppler radar and laser techniques (Lidar). Each of these has its own raw data form, accuracy, limitations and error sources which, ideally, must be included in the reduction of the data to velocity time and position histories and their spectral characteristics. Location, time of year and ambient weather conditions may be recorded also for correlation information.

Wind measurement data has been gathered for many years at the ETR and WTR launch sites, but the database in use for Titan IV is fairly limited. It consists of approximately one thousand wind profiles. Expansion of the database and, in particular, improvement of the time correlation data (wind persistence) would be very desirable. Increased confidence in analyses given better wind data should permit decreased margins and increased performance.

The essential elements of local wind modeling based on measurement are illustrated below. This diagram provides an idealized system overview of the function-data flow.

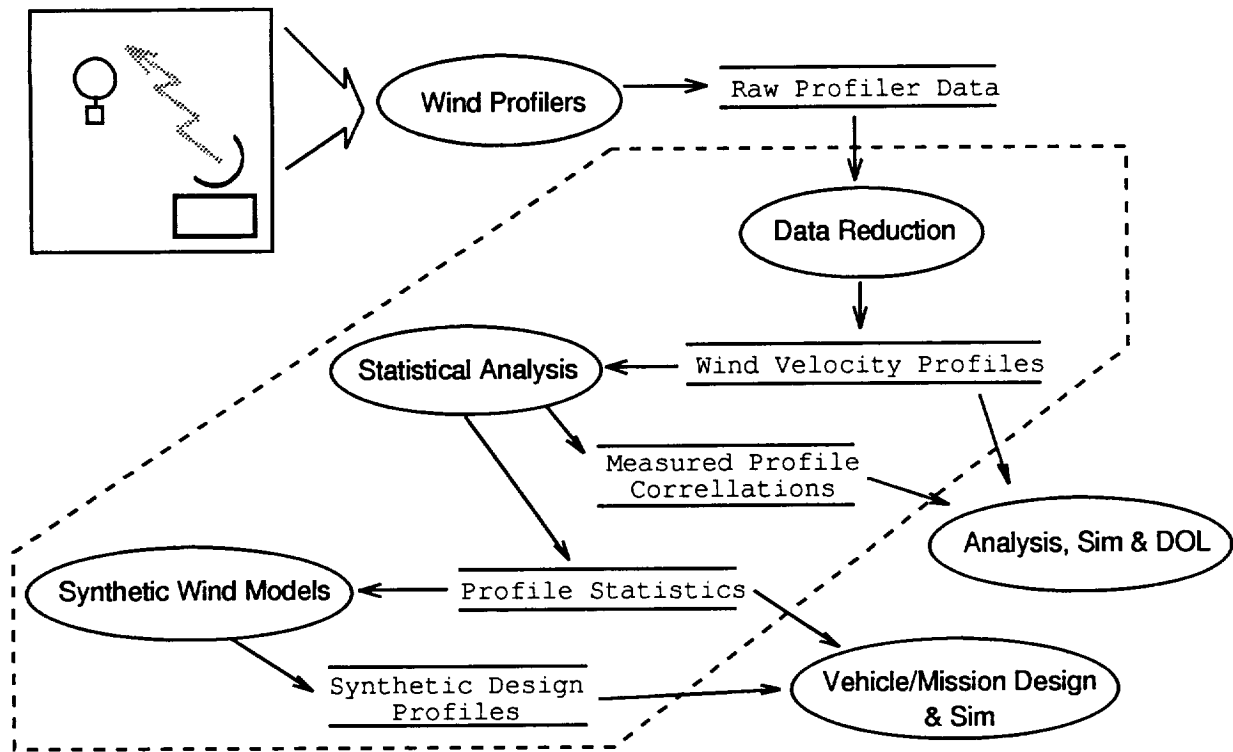


Figure 2-1. Wind Modeling Processes and Products.

2.2 Titan IV Functional Groups

The payload integration process for the Titan IV vehicle is performed by a number of functional groups. The organizations and their roles are outlined in Figure 2-2. The groups indicated by boldface are those which employ some form of wind data or models in their design and analysis processes.

During launch operations, the groups have similar relationships although their functions differ somewhat. Day of launch measured winds are employed to design the launch trajectory, guidance parameters are generated, and subsequently measured profiles are used to validate the flight load that is uplinked to the vehicle prior to launch.

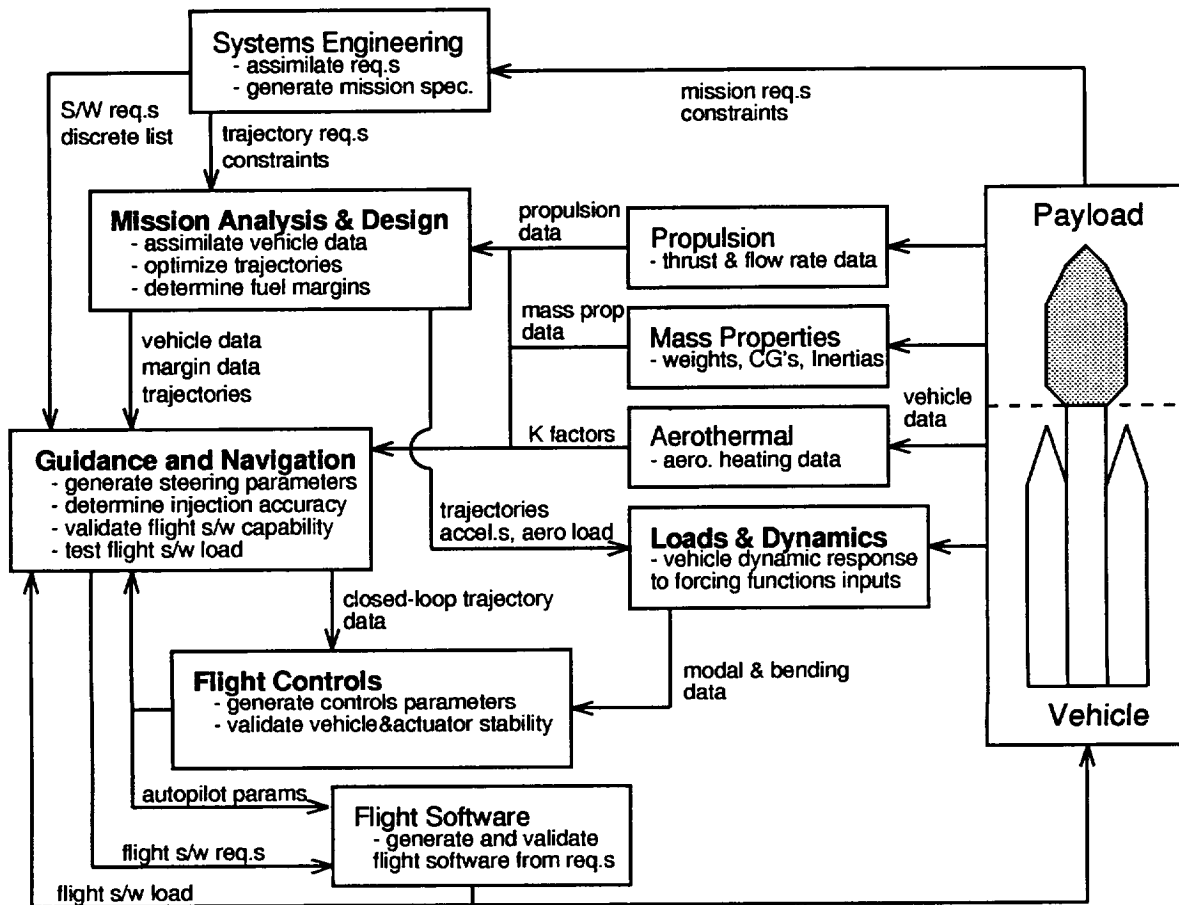


Figure 2-2. Current Titan Payload Integration Functions

3. Current Titan IV Processes Involving Winds

The following summarizes the descriptions obtained from each of the groups highlighted in Figure 2-2 about their processes that use wind data and/or wind models.

3.1 Mission Analysis and Design

Mission Analysis and Design (MA&D) is the major user of wind data and appears to be the effective 'custodian' of the wind data presently employed during Titan IV payload integration. Other functional groups requiring wind velocity profile data generally indicated that this are supplied to them by MA&D. Also, wind-related analyses performed by other groups often employ the results of simulations in a wind environment run by MA&D rather than using wind data directly. For example, Loads and Dynamics derives wind loading information based on $Q\alpha$ and $Q\beta$ time histories provided by MA&D.

A summary of the current wind data and model usage by MA&D follows:

3.1.1 Processes requiring wind models or data

- All launch constraint (placard) analyses, including:
 - Loads
 - TVA (thrust vector actuator) voltage
 - TVC (thrust vector control) usage
 - SRMU (solid rocket motor upgrade) gimbal angles
- Stage II propellant margin analysis
- Venting analysis
- Aeroheating analysis
- Launch drift analysis
- Range safety analysis
- Nominal trajectory shaping, including Day-of-Launch
- Post-flight trajectory reconstruction (6D and TD213)

3.1.2 Type of Wind Information Required

- Wind speed and direction profiles (azimuth) vs. altitude
- Probability levels of velocity magnitudes vs. altitude
- For given probability level, wind speed scale factor vs. altitude
- Wind shear rates vs. altitude for various probability levels
- For synthetic wind profiles, length of wind shear

3.1.3 Wind Data and Models Presently Employed

Data / Model Type	Sources	Applications / Comments
Real Wind Data (above 500 ft) <ul style="list-style-type: none"> - Single and time-related pairs - Typically balloon sounding data 	<ul style="list-style-type: none"> - Aerospace Report - MSFC - Recent DOL tests - Special data collection programs - Range Daily Synoptic Rawinsonde data 	<ul style="list-style-type: none"> - Trajectory Shaping with 3D POST, data smoothed with 1Kft - 2 Kft window "dumb" filter - Simulations with MSSS use unsmoothed data - data lacking above 50 Kft
Wind Persistence Models: <ul style="list-style-type: none"> - NASA model for ETR - MMC MA&D-defined model for WTR (based on measured wind-pair data) 	<ul style="list-style-type: none"> - NASA - MMC 	<ul style="list-style-type: none"> - 0.5 hr, 4 hr, 6 hr pairs for simulation of trajectory in dispersed winds & statistical analysis of the results - database is thin, causing large margin requirements
Synthetic Wind Profiles: <ul style="list-style-type: none"> - Range Reference Atmosphere monthly mean wind profiles and bivariate normal probability ellipses vs. altitude, ETR and WTR - Meteorological Note #2 (Data Book) outer envelope profiles shear rate profiles vs. altitude and probability wind speed scale factor vs. azimuth - NASA Ground Wind Profile exponential function vs. altitude based on anemometer data 	<ul style="list-style-type: none"> - MSFC - NASA 	<ul style="list-style-type: none"> - Performance Studies - TVC placarding - TVA placarding - SRMU gimbal angle placarding - launch drift analysis (pad ~ 2 Kft)

3.1.4 Wind Persistence Analysis

Persistence analysis is the process whereby margins and placards related to wind dispersions are established. It is critical to launch availability and performance.

The present synthetic wind models are unusable for persistence analysis because the synthetic wind profiles generate vehicle responses that are very different from the responses obtained when using measured wind profiles. Clearly, the synthetic wind profiles are not accurately modeling the true characteristics (spectral content) of the actual winds.

Therefore, pairs of winds from a database of historic profiles are employed to obtain statistics for vehicle load variations due to wind dispersions. The current process is illustrated in Figure 3-1.

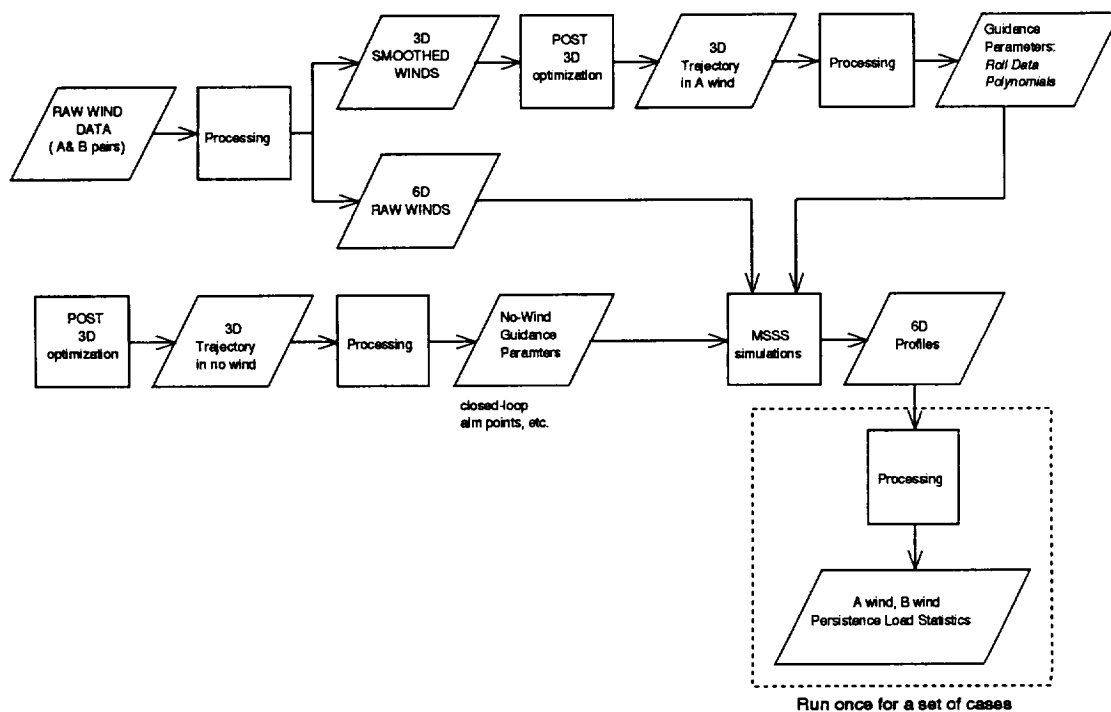


Figure: 3-1. Present TIV wind persistence analysis process.

During the Day-of-Launch activities, wind measurements are taken repeatedly at approximately two hour intervals using radar-tracked balloons. MA&D designs the DOL trajectory with one wind prelaunch-measured wind profile and then simulates that trajectory flown through a subsequently measured wind to validate it. A balloon is also released at vehicle launch to measure the actual winds encountered during ascent. (Of course, the accuracy of the balloon measurement is impacted by positional errors with respect to the ascent trajectory). It has been found that the correlation in loads between the design trajectory and the actual trajectory is very low, but that the correlation between the validation simulation and the actual trajectory is better. This is summarized in Figure 3-2.

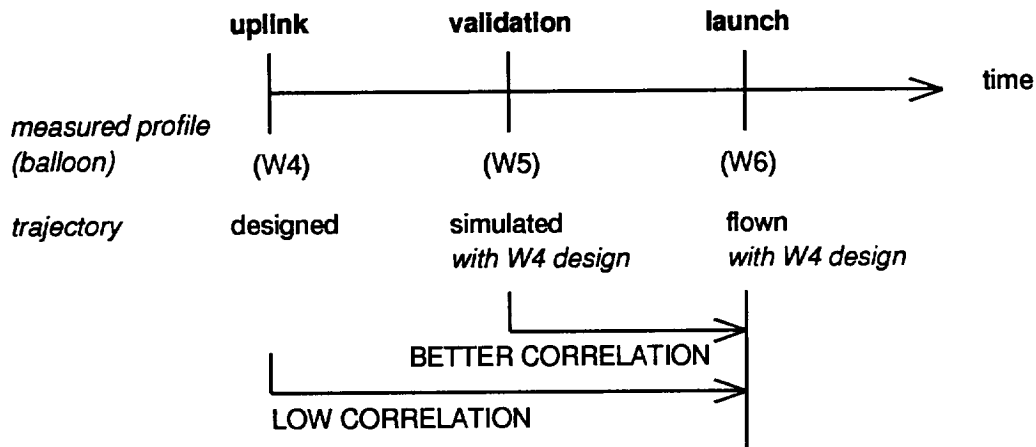


Figure 3-2. Loads correlation on day-of-launch.

An improved wind persistence model would be very useful in this process if it allowed a reductions in margins required in the designed trajectory. Performance may be enhanced.

3.2 Guidance and Navigation

Guidance and Navigation analysis (GNA) currently makes only limited direct use of wind data. Typically, GNA is provided the output of the multiple wind pair simulations performed by MA&D and extracts from them the relevant guidance variables which may be checked for ranges and statistics. (Range checking is important on the current, fixed-point MGC flight computer.)

During the verification process, GNA employs a set of $\pm 3\sigma$ maximum/minimum synthetic wind profiles for use in 6-DOF MSSS simulations. These are provided by MA&D. During the "omnibus" run, a 99% envelope wind profile is used. This is intended to 'stress' the flight software and is a highly unrealistic case. In all of these analyses, the objective is to validate the *functioning* of the guidance flight software rather than accurately model vehicle performance in the wind environment.

During the DOL activities, GNA validates the output of the simulation done with each balloon-measured wind profile. Sensitive variables are checked for their range and the sequencing of events and discretizes are checked.

In the future, given a suitable database or synthetic wind model, GNA may undertake to perform independent simulations and statistical analyses in order to improve guidance accuracy and performance.

3.3 Flight Controls

Flight controls designs the vehicle autopilot to maintain vehicle and actuator stability while tracking the commands generated by the vehicle steering.

The present flight controls process does not employ winds data directly. The autopilot parameters are designed for the given vehicle configuration and payload. The design is subsequently analyzed in simulation by Loads and Dynamics. If the vehicle response fails certain loads criteria, Flight Controls must adjust a gain parameter that impacts load relief and re-iterate the process.

With the H₂/SANDY autopilot design process currently being introduced into the Flight Controls design process the design algorithm has the capability to include information describing the wind characteristics. Load relief thus may be explicitly included in the autopilot design. The wind data is provide to the algorithm in a frequency-domain form such as a power-spectral density (psd) function.

At present, only a simple psd derived from a 1965 report is available for use. Expansion and extension of the wind profile database and application of suitable statistical analysis techniques to the data should provide vastly improved inputs to the Flight Controls design process.

3.4 Loads and Dynamics

The Loads and Dynamics group is responsible for the analysis of the structural dynamics and response of the vehicle to imposed loads, including aerodynamic loads.

Velocity vs. altitude profiles are used for some simulations and for wind shear analyses. However, for the majority of studies, from nominal and dispersed trajectories are provided to L&D by MA&D. These are used as inputs to the loads analyses and wind data is not directly used.

During Day-of-Launch activities, Loads Analysis derives their validation results using $Q\alpha$ and $Q\beta$ profiles from the MA&D simulations

For some analyses, such as gust loading, abstracted models are used.

Gust loading on the vehicle is a major component of the total loads budget. It is simulated using a $1-\cos(\text{altitude})$ wind gust profile with a maximum magnitude of 30 fps and an altitude width ranging from 200 ft to 1500 ft. This form is based on historical usage (NASA) and 'hits' the vehicle with a gust that stresses the structure and is too fast for the autopilot to respond. Studies with an expanded wind database eventually may be used to verify that this is a reasonable model to use or to suggest less (or more) conservative approaches. It is thought that the assumed model is very conservative.

4. Other Launch Systems to be Supported

In addition to Titan IV, Lockheed Martin is involved with a number of other launch systems for which enhanced wind sensing, analysis and modeling would bring operational advantages.

Atlas is a major medium-class launch system operated by Lockheed Martin. The current usage of wind data in the analysis, design and operation of the Atlas vehicles was not identified under the present effort. In general, the vehicle is less sensitive to winds than the larger Titan IV, but improved wind data would be expected to have positive performance or flight availability impacts.

EELV is the next-generation, Evolutionary Expendable Launch Vehicle, currently under development by Lockheed Martin. Improved wind data and methods will enhance the ability to meet the reduced-cost operational goals.

X-33/RLV, the Reusable Launch Vehicle, is currently under development by Lockheed Martin. This is an audacious program to develop a reusable, single stage to orbit (SSTO) launch system. The X-33 will be a sub-scale, sub-orbital research vehicle used to test and validate the necessary technologies and processes. Both the planned X-33 flight test program and the eventual production RLV have requirements for high operability and high flight rates. Sensitivity to winds during ascent and during approach and landing may be a serious issue. Good wind data will be needed for system design. An efficient, highly automated wind profile sensing and analysis system may be required to support operations during launch, ascent and return.

5. Wind Sensing Methods

A number of meteorological profiling methods are in use or are under development. A general framework for wind sensing, analysis and modeling, and its supporting information system infrastructure, should be established to accommodate all of these.

5.1 Existing Systems

Wind profiles in the launch environment have been measured for many years using balloon-based systems. At the Eastern and Western Ranges, the Meteorological Sounding System (MSS) has been used, as well as the radar-tracked Jimsphere balloon. The former system is a radar-tracked, radiosonde system which returns wind, temperature, relative humidity and pressure data. The latter makes use of the Range's tracking radar systems to obtain more accurate wind velocity data as the balloon ascends through the atmosphere.

Both of these systems are quite costly to operate. The equipment used by the MSS system is aging and reaching the end of its operational life. The Jimsphere system's reliance on Range radar limits its flexibility and adds operational complexity.

An additional consideration is that balloon-based systems yield data that is influenced by their flight time, which is approximately one hour, and spatially by their drift in the wind field. These effects need to be accounted for in the data reduction analyses.

For Space Shuttle operations, local wind environment data also is gathered by instrumented aircraft flying in the vicinity of the launch and landing sites. This approach, however, has limited coverage and is a very expensive operational burden.

5.2 Automated Meteorological Profiling System

The Automated Meteorological Profiling System (AMPS) is currently under development for the USAF. This system is intended to supersede the MSS balloon system and to augment the continued use of Jimspheres. The objective is for an economical and flexible means of obtaining atmospheric soundings.

It is highly probable that this system will use inexpensive, GPS (Global Positioning System) transceiver-equipped balloons, although other approaches have not been excluded. Radiosonde balloons with GPS (and other meteorological sensors) transmitting their data to a compact, workstation-based ground element for processing could provide a system that is operationally simple, flexible and potentially mobile. The major drawbacks of such a system remain the flight time and spatial effects inherent to balloon-based approaches. However, the ability to obtain data simultaneously from multiple balloons launched over a period of time and from separated sites should be feasible for such a system. This could provide measurement data allowing mitigation of the flight time and spatial effects. The current specification for the AMPS system calls for the capability for up to

four balloons (flight elements) to be supported at a time by a single ground station.

Since this system is under development, any general approaches for wind sensing, analysis and modeling should be compatible with the AMPS system and its data product.

5.3 Doppler Radar

Radar-based wind profiling has undergone considerable recent development. A 50Mhz Doppler wind profiler has been developed and has been operated at the Eastern Test Range in support of Shuttle launch operations. The current use has been focused on detection of features in the prelaunch wind field that might have been missed by the balloon systems. (The balloon data remains the primary data for analysis.) The system makes use of the backscatter from index-of-refraction inhomogeneities in the atmosphere.

One disadvantage of Doppler radar profilers is that a large, fixed infrastructure (for example a 10m dish antenna) is required for systems having the altitude capability needed to support launch and entry operations (20+km). This is an operational concern, particularly for systems such as RLV which might launch and land at multiple sites, all of which would need to be equipped.

Doppler radar also is limited in that it senses the wind in fairly large sample volumes. Current systems also have been reported to exhibit some sensitivity to disturbances caused by passing vehicles.

The advantages of Doppler radar profilers are a good all-weather capability, which is an operational asset, as well as the ability of a matured system to provide almost real-time wind profile measurement.

The use of a Doppler radar wind profiler to supplement or replace the balloon data employed by the Titan IV day-of-launch (DOL) analysis and design processes is under investigation.

5.4 Laser Sensing (Lidar)

A division of Lockheed Martin, Missiles & Space, has developed a prototype wind profiler employing a lidar-based system. The system employs the backscatter signal from aerosols suspended in the atmosphere. It has been demonstrated at the Kennedy Space Flight Center as well as near Boulder, Colorado.

The potential advantages of the system include the ability to profile wind velocities along a relatively narrow corridor rather than in a larger volume above the sensing site. Comparatively high velocity measurement accuracies and altitude resolution have been demonstrated, as has the ability to obtain data at the maximum altitudes needed to support launch system operations (20-26km, under favorable conditions).

As with Doppler radar-based systems, a mature lidar-based system has the potential of providing near real-time wind profiles. The prototype system can produce 3 degree-of-freedom wind field

measurements along a corridor defined by a 10 degree cone angle, in approximately 3 minutes. A mature system also is expected to be realized with a flexible, mobile hardware system. The current prototype is contained in a road-mobile trailer.

A major drawback of lidar-based systems is its sensitivity to cloud obscuration. Thin clouds and some precipitation can be tolerated, but significant cloud cover of depth can block the laser signal. This lack of all-weather capability may limit the operational usefulness of lidar-based systems. However, the potentially high resolution, accuracy and pointability suggests that lidar-based sensing might be a valuable adjunct to other methods, particularly at sites having favorable weather conditions.

An additional concern to the current launch community is that the system's performance must be verified and validated to a greater degree (with respect to Jimsphere data, for example). It is hoped that development of the system will be continued and more testing perhaps in conjunction with flight operations of the Shuttle, other launchers, or the X-33 vehicle, will be accomplished.

As development of the lidar-based system is continued, it would be desirable for the analysis methods associated with it and the data developed to be captured in a fashion compatible with the general wind sensing, analysis and modeling methods.

6. Information System Infrastructure

Experience gained on several programs and development efforts under IR&D activities at Lockheed Martin have lead to the current approach to GN&C systems engineering. Driven by necessity on programs such as TOS (Transfer Orbit Stage) and MSLS (Multi-Service Launch System), methods and tools have been developed enabling significant automation of recurring GN&C engineering processes. Captured in such automated processes, the engineering has also proved to be very reusable. Wind profiling is an activity supporting GN&C. It is the objective to facilitate those analyses and processes by capturing them in a fashion compatible with the supported GN&C processes.

Tools developed in a hypermedia environment running on UNIX workstations enabled, for example, the design and analysis of the TOS control system to be accomplished with ten man-hours of effort, automatically generating the contract deliverable design document. Previously, the effort took six to twelve man-months and was less repeatable and reliable. Additionally, the TOS engineering was extensively reused to rapidly generate complete prototype designs for three different configurations of the PFF (Pluto Fast Fly-by) vehicle. Accomplished in 10 man-weeks, this effort reused approximately 90% of the TOS engineering, despite a major change in vehicle physical configuration between the two programs.

The tools and methods employed on these cited examples have been incrementally developed. A major lesson learned has been that the tools and usage methodology themselves, the *information system infrastructure*, must be properly designed from the outset. If this is not done, the tools may not prove to be maintainable or extensible. Further, while the processes and actual engineering performed were specific cases of GN&C applications the concepts and methods are applicable to other subsystems as well as to the overall system.

For the purposes of capturing the algorithms and processes used in the analysis and modeling of winds, the latest versions of the Lockheed Martin PME prototype tools were to be used. These are being provided to the customer. They are realized in the KMS hypermedia environment.

The key tool is the latest prototype version of the "Script Tool". This tool may be employed to capture, manage, execute and document analysis and simulation algorithm source code. This version supersedes prior versions of the Script Tool. *A utility is provided that allows instances of prior versions of the Script Tool to be cloned into upgraded form.* The new version provides numerous enhancements, which include:

1. Multiple scripts within a single frameset.
2. Enhanced version/release control
3. Enhanced customizable templates for script frames
4. Line numbering of the source code and a goto line number function to assist in debugging.

An important feature of the latest version is that is implemented in a quasi-object-oriented fashion as part of a more integrated set of PME tools, although this is largely transparent to the user.

The delivered PME prototype also contains the "Auto Process". This is a capability that permits the

documentation of analysis and design processes through function-data flow diagrams and the automatic execution of those processes. These processes may consist of, for example, the execution of a sequence of codes captured as instances of the Script Tool. The AutoProcess prototype is not yet fully documented (no Help screens are provided). At a future opportunity, perhaps associated with collaborative efforts on current or future joint activities, Lockheed Martin will familiarize the customer with the use of this tool. In order for us to develop it, the "alpha testing" of its capabilities and usage by the customer would be encouraged by Lockheed Martin.

A variety of other PME utilities may be accessed from the General Palette (found on KMS frame "aPMESet6"). These include buttons to access general UNIX utilities as well as three indexing functions. The indexing functions can be employed to create 'snapshot' indices of free-form data trees within the KMS database. The Engineering Notebook found in the delivered database is essentially a bare-bones template that does not have the complex functionality of the "Version:0, 1993 June 1" version (nor the performance problems which that version exhibited under later versions of KMS).

The delivered versions of the PME prototype tools are restricted to use by the customer internally or during joint activities with Lockheed Martin and must be protected from usage or access by third parties. The computer software underlying and realizing the PME functionality is copyrighted by Lockheed Martin. However, this shall not constrain the customer from showing or demonstrating to third parties the customer's own work that is captured using these tools.

7. Summary of Wind Model Requirements

The following are general requirements abstracted from our Titan IV experience and reflecting our approach to engineering processes. These are *shoulds*, desirable features for a future, unified approach to wind modeling. The objective is to support the design and flight activities of enhanced existing launch systems and future systems, such as RLV, which have the need for increased operability and decreased cost.

7.1 Wind Modeling Infrastructure

The algorithms and processes applied to wind modeling should be captured within the same, integrated information system infrastructure as is used to support the launch system analysis, design and operational activities. The Lockheed Martin PME is the prototype for such a system and illustrates the approach to process automation, tool integration and the associated interfaces for the developer and user groups.

The current Script Tool and AutoProcess offer the capability to capture and document the development and prototypes for analysis codes (in Matlab™, Xmath™, FORTRAN, C, etc.) and the process of executing them.

If systems are implemented on disparate platforms and under different software systems, it is highly desirable that they be designed in an open-architecture or extensible fashion with communications capabilities allowing them to be 'glued' into larger processes supporting launch operations. The system should have the documentation of its capabilities, limitations, and theoretical basis fully captured in conjunction with its software development.

7.2 Wind Sensing Methods

To best support enhancements to current launch systems and to support future systems it is probably that a combination of sensing methods for measuring wind profiles should be applied. It is therefore desirable the analysis methods and processes be captured and documented in a common fashion to facilitate the comparison of methods and combination of methods. At a minimum, systems should be designed with defined data and functional interfaces that allow them to communicate and operate with other systems (especially in automated modes). Stand-alone approaches that simply yield a specialized data output are undesirable. Also, the establishment and use of a common Meteorological Profile Database should be pursued to support combined system operations.

The characteristics desired for wind sensing methods to support high operability goals include: minimized installation infrastructure, automated/autonomous sensing and data reduction, data output in common formats, clear goodness-of-data indicators and error analysis, real-time data reduction, low cost operation.

7.3 Meteorological Profile Database

An extensible but common database approach should be defined for measured wind profile data. Improved analysis of the statistical characteristics of the wind field on local, regional and temporal bases requires access to larger sample sets. Collaboration between all agencies gathering such data would be of great benefit to all in the national launch community. A common database approach would facilitate this.

For example, Titan IV operations would benefit from a greatly expanded sample set at the ETR and WTR launch sites providing more data supporting persistence analysis, time of year correlation, and high altitude conditions (in excess of 65Kft).

The data reduction system employed in conjunction with specific wind profile measurement methods should include, if required, translators that can map the profile data generated by the profiler into one or more of the standard formats defined for the database. The objective is to permit decoupling of the sensing and data reduction methods from the wind analysis and modeling methods. This will enable changes and improvements in either to be accomplished without requiring changes in the processes and tools employed by the other.

An effort to establish and maintain the definitions of these standard formats will be required. (It may be the case that the meteorological community already has accomplished this to some degree). Measured profile data should include parameters reflecting spatial, temporal and error characteristics.

An effort to identify and collect the considerable wind data that already has been gathered in the past by numerous agencies is also needed.

7.4 Wind Statistical Analysis and Synthetic Wind Models

Synthetic wind models and profile statistics are employed primarily for system design and preliminary trajectory targeting. Profile statistics, often a function of location and season, are employed by the model algorithm to produce synthetic time or altitude histories of wind profiles for use in analysis, design or simulation. The statistics also may be used to produce spectral content (e.g. PSD) inputs to activities such as autopilot design.

Current synthetic wind models normally assume a distribution function when representing wind statistics. Most commonly, the horizontal components of a wind field are represented by a bivariate normal distribution. This assumption does not necessarily provide an accurate model of the wind's spectral content. Improved synthetic wind models should provide the ability to better represent the actual, measured statistics of the wind field.

Such improved models should result in analyzed and simulated vehicle responses, both in the time and in the frequency domain, to be similar to those produced when employing measured wind data.

Inclusion of wind persistence statistics is highly desirable. Persistence models should be improved as the database of measured wind profiles is expanded and analyzed. Persistence with respect to spatial

variation as well as time should be analyzed, particularly when it impacts the analysis of measured data.

The development of analysis and modeling methods should be performed in a PME-type environment to ensure that the capabilities, limitations, and employment of specific model formulations is captured.